INSTRUCTION MANUAL

MODEL 503

MILLIOHMMETER

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof, except tubes, transistors, fuses, and batteries, which, within a year after shipment to the original buyer, proves defective on examination.

DAMAGE IN SHIPMENT

Be sure to include the instrument model number and serial number in all communications.

If the instrument is damaged when received, or fails to operate properly, a claim should be filed with the carrier. Upon receipt of the claim agent's report, we will inform you regarding repair or replacement.

REPAIRS

When returning an instrument for repair or recalibration, it should be securely packed against shipping damage and sent to the factory, freight prepaid. A brief letter describing the difficulty should accompany the instrument.

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SECTION I - INTRODUCTION

The Keithley Model 503 Milliohmmeter is designed to measure low value resistances from 0.001 ohm, full scale, to 1000 ohms, full scale. It is line powered and direct reading and has a provision for chart recording.

It is capable of an accuracy of 1% of full scale for meter indications and 0.5% of full scale for the output voltage.

An AC measuring system is employed to minimize test current through the test sample and at the same time realize drift free operation. This technique also eliminates errors due to thermal EMF's.

The instrument is completely self contained and includes test leads (Model 5301) for connection to the sample. It is readily convertable to either bench or rack mounting.

FIGURE 1. Model 503 equipped for bench use

SECTION II - SPECIFICATIONS

RANGES: the test current, the input voltage drop, and sample power dissipation for full scale reading are given below in Table 1.

TABLE 1

Range Ohms	Applied Current ma rms	Voltage Drop uv rms	Maximum Power in Sample Microwatts
0.001	100	100	10
0.003	33	100	3.3
0.010	10	100	1.0
0.030	3.3	100	0.33
0.10	1.0	100	0.10
0.30	0.33	100	0.033
1.0	3.0	3000	9
3.0	1.0	3000	3
10	0.3	3000	0.9
30	0.10	3000	0.3
100	0.03	3000	0.09
300	0.01	3000	0.03
1000	0.003	3000	0.009

ACCURACY: One percent (1%) of full scale on all ranges for meter indications. One half percent (0.5%) of full scale on all ranges at output voltage terminals. Less than 1% error is added in measuring samples with a series reactance less than 2% of sample resistance.

OUTPUT CHARACTERISTICS: +100 millivolts dc at full scale, output impedance of approximately 800 ohms, output noise above 10 cps, less than 1 millivolt rms.

SAFETY AND RELIABILITY: Maximum power dissipation in sample with improper range setting is 80 milliwatts. Maximum dissipation caused by instrument component failure and improper range setting is 160 milliwatts.

INPUT ZERO: Lever switch prevents off scale meter indications while changing samples.

SPEED OF RESPONSE: 0.25 second to 90% full scale on all ranges.

ZERO DRIFT: None

REPEATABILITY: Within 0.25% of full scale range setting.

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CALIBRATION: Provision for verification and adjustment on front panel.

POWER REQUIREMENT: 105-125 volts 50-1000 cps, 30 watts. May be wired for 210-250 volt line.

WARM-UP TIME: 15 minutes

TUBE COMPLEMENT: 1-12AX7, 1-6U8A

TRANSISTOR COMPLEMENT: 1-2N1535, 3-2N1183, 4-2N1381

ACCESSORIES FURNISHED: Two test lead sets, 1 pair rack mounting brackets, 1 cover for rack mounting and mating output connector.

CONNECTORS: Test Leads, cannon XLR-3-32, output Amphenol 80-PC2F, mating plug 80-MC2M. Model 503C: Relay output, Amphenol 126-221 mating plug 126-222.

DIMENSIONS: Bench Mounting: $17\frac{1}{2}$" wide x $13\frac{1}{2}$" deep x $5\frac{1}{2}$" high. Net weight $17\frac{1}{2}$ lbs. Rack Mounting: $19\frac{1}{4}$" wide x $13\frac{1}{2}$" deep x $5\frac{1}{4}$" high. Net weight $17\frac{1}{2}$ lbs.

SECTION III - GENERAL DESCRIPTION

A. APPLICATIONS: The Keithley Model 503 Milliohmmeter is especially useful for accurate measurement of low value resistors; resistances of lead wires, terminal connector contacts and welds; resistance change in conductors due to temperature and humidity effects; resistance of ohmic junctions in semiconductors; resistivity of semiconductors, contact resistance of vibrators, relays and choppers and internal resistance of dry cells. Also for resistivity profiles of thermoelectric materials and safe measurement of squibs and fuses.

B. MEASUREMENT TECHNIQUE:

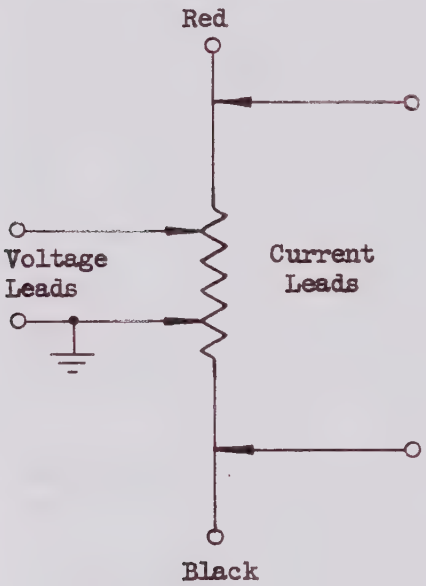


Figure 2

The Model 503 measures resistance by an ammeter-voltmeter method using an ac test current. Four terminals are employed; two furnish a known test current to the sample and two measure the resultant voltage drop.(Fig. 1) The voltage is measured by a synchronous ac voltmeter sensitive only to the test current frequency.

Most Kelvin resistance methods employ dc current to measure resistance. This method has the advantage of measuring only the resistive portion of the sample. However, due to the extremely low resistance being measured either extremely high currents must be passed through the sample or very high sensitivity dc voltmeter techniques must be used to measure the voltage drop across the sample. In the case of high current operation (which is the more common) excessive heating and damage to the sample may occur. If high sensitivity DC voltage measurement is used, extreme inaccuracy may occur because of thermal EMF's and other spurious dc disturbances. With the AC method used in the Model 503, there exists some possibility of error due to the reactive component of the sample (Section IV-F) although in most cases at 40 cps testing frequency this is negligible. However, with an ac exciting test current, thermal EMF's are eliminated and very stable high sensitivity measurements can be made so that with this AC method sample dissipation can be held 10 microwatts in measuring a 1 milliohm sample. (Table 1 - Specifications) A typical dissipation on a DC Kelvin Bridge is 1 watt for the same measurement.

C. ACCURACY: The accuracy of the measurement can be dependent on several factors. These are discussed in Section IV-G. The basic accuracy of the 503 is within 1% of full scale for meter indications and 0.5% for full scale output voltage.

D. REPEATABILITY: Having once established a reading for a particular sample measurement, it is possible to repeat within 0.25% of the full scale range setting. This assumes the connections to the sample remain fixed.

E. CALIBRATION: The 503 is self calibrating and thus reduces the need for resistance standards to check its accuracy. It is possible to verify the calibration with or without the sample attached to the test leads. (See Sect. IV-C)

F. VOLTMETER SPECIFICATIONS: Since the 503 uses a synchronous demodulator, the voltmeter is sensitive only to signals of the test current frequency. The sensitivity and input impedance are listed in Table 2.

TABLE 2

Ranges	Rms Input for Full Scale Deflection	Z in
Milliohm	100 uv	200 ohms
Ohm	3000 uv	1×10^6 ohms

G. TEST CURRENT CHARACTERISTICS: The test current is a square wave derived from the transistor inverter. The frequency is about 40 cps, and can be adjusted as discussed in Section V-B. This may be desirable if the power line frequency is a multiple of 40 cps.

The maximum open circuit voltage is no more than 20 volts peak to peak. No more than 80 milliwatts of power can be delivered from this source.

H. SPEED OF MEASUREMENT: Fast measurements are possible by virtue of an overall 0.25 second response (90% full scale) of the output voltage. A zero switch on the front panel shorts the input to the voltage amplifier, thus preventing off scale indication while changing samples. Recovery from overload is almost instantaneous and normal operation can be immediately resumed.

I. WARM-UP: Operation within the stated specification is assured if the 503 has a 15 minute period of warm-up. It can be used within one minute, but measurements may not be within the accuracy specification.

J. RECORDING: Output terminals are available at the rear of the instrument. The output is +100 millivolts across approximately 800 ohms. The output noise level, above 10 cps, is less than 1 millivolt rms. This output is suitable for driving digital voltmeters and servo-rebalance recorders. The accuracy of the output is 0.5% of full scale.

K. POWER REQUIREMENT: The Model 503 can be powered over a range of line frequencies from 50 cps to 1000 cps. The line voltages can range from either 105 to 125 volts or 210 to 250 volts. No special connections or modifications are required to operate over the range of power line frequencies.

A three prong power line cord is provided, this is to assure proper grounding of the instrument to the power line.

L. RACK OR CABINET MOUNTING: The 503 can be used as bench or rack mounted instrument. It is shipped as a bench mounting model, but included in the shipment is a kit for converting the 503 to a rack model. (See Section IV-G)

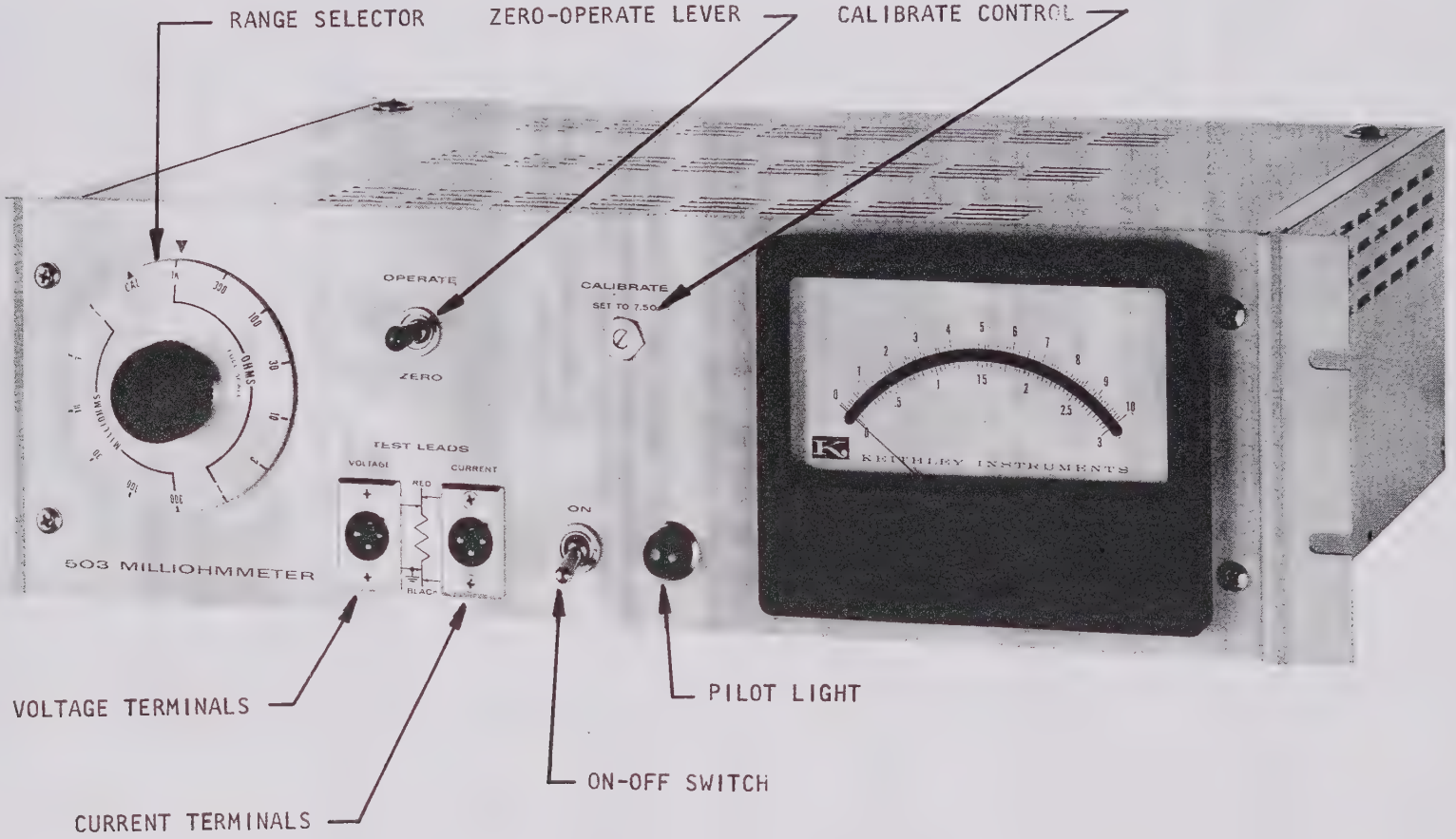


FIGURE 3. MODEL 503 EQUIPPED FOR RACK MOUNTING

SECTION IV - OPERATION

A. DESCRIPTION OF CONTROLS AND TERMINALS:

1. RANGE SELECTOR: The RANGE SELECTOR has six milliohm positions ranging from 1 milliohm to 300 milliohms, and seven ohm positions ranging from 1 ohm to 1000 ohms. A CAL position is provided for instrument calibration. (Fig. 3)

2. ON: Toggle switch is the main power switch. Presence of power is indicated by the illuminated front panel pilot lamp. (Fig. 3)

3. OPERATE-ZERO: This is a lever switch. With the switch in the up (operate) position the 503 is ready to take measurements. In the down (zero) position the 503 is in zero check. (Fig. 3)

4. CALIBRATE: This control is used to calibrate the meter and the output voltage of the 503. It is a recessed slotted control that can be adjusted with a screw driver. (Fig. 3)

5. VOLTAGE TERMINALS: A 3 pin male receptacle is used for connection to the voltmeter circuit. Pin #2 is at chassis ground. Either test lead can be plugged into this receptacle. (Fig. 3)

6. CURRENT TERMINALS: A 3 pin male receptacle is used for connection to the current source. Pin #1 is at chassis ground. Either test lead can be plugged into this receptacle. (Fig. 3)

7. OUTPUT: A two terminal receptacle is located at the rear of the chassis. This provides the output voltage for recording. Pin #2 is at chassis ground.

8. RESET (503C ONLY): This unlocks the contact circuit. A 9 pin receptacle at the rear of the chassis provides connections for operation with the contact meter.

9. OUTPUT CAL: This is a slotted control located inside the instrument on the chassis behind the front panel. This adjusts the value of the output voltage for a full scale reading.

10. MILLIOHMS CAL: This is a slotted control located inside the instrument on the chassis behind the front panel. The milliohm ranges are calibrated using this control. A low resistance standard is required for its use. This is a factory adjusted control and should not require attention.

11. FUSE: A fuse extractor post is located on the rear of the instrument. For 117 volt operation use a 3 AG, $\frac{1}{2}$ amp. fuse; for 234 volts use a 3 AG, $\frac{1}{4}$ amp.

12. POWER CORD: The three wire cord with the NEMA approved three-prong plug provides a ground connection for the cabinet. An adapter to allow operation from two prong outlets is provided.

B. OUTLINE OF PROCEDURE:

1. Connect power cord to power source. A three wire power cord is furnished with the 503. Power line voltage and frequency range are specified on the rear of the instrument.

2. Set ZERO-OPERATE lever to the ZERO position. Set RANGE SELECTOR to 1000 ohm position.

3. Turn on the power. Allow 15 minute warm-up.

4. CONNECTIONS: Each test lead set has two clips, one with a red insulator and the other with a black insulator. When making connections use both test leads, making sure clips with like color insulators are on the same side of the sample. (Refer to Figure 2) This is necessary to avoid meter readings below zero.

a. Four terminal connections: The current leads should be attached to the sample making sure the test current flows through the entire sample. This may include leads on the sample. Attach the voltage leads being sure they are connected only across that portion of the sample to be measured. If the terminals or the leads of the sample are included in the voltmeter circuit, their resistance will be included in the reading. (See Section IV-F)

b. Two terminal connections: This type connection is made by attaching together voltage and current clips having like color insulators and measuring across the sample. (Fig. 4) This type connection is permissible when measuring samples above 3 ohms. (See Section IV-F)

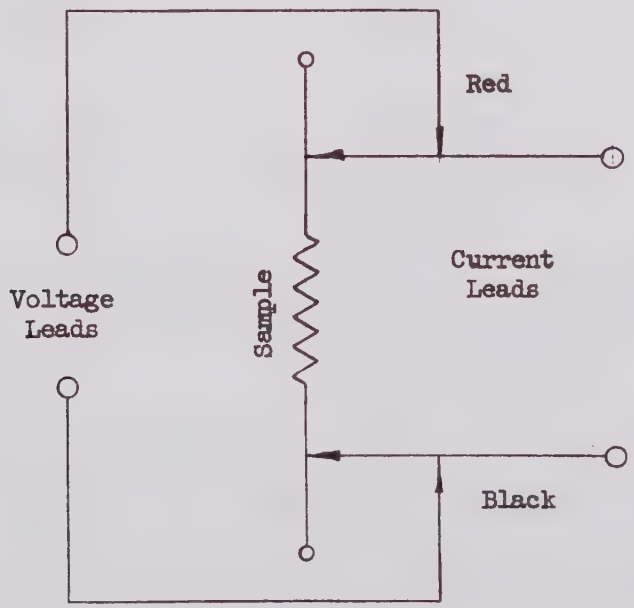


Figure 4

5. OPERATION: With the sample connected, set the ZERO-OPERATE switch to OPERATE, rotate the RANGE SELECTOR until a deflection is observed. Thus, if the RANGE SELECTOR is set at 100 milliohms and a reading of 6.3 is taken, the value of sample resistance is 63 milliohms.

If the sample is part of a system, attention should be given to the grounding of the sample. The voltage lead with the black insulator is the ground lead of the 503. (See Section V-D)

6. REMOVING THE SAMPLE: Place the OPERATE-ZERO switch in ZERO position and remove the sample.

C. CALIBRATION: Place the selector switch in CAL position. Set the OPERATE-ZERO switch to OPERATE position. Turn the slotted CALIBRATE control for needle deflection to 7.50 on the meter. The instrument can be calibrated independently of the test leads connected. (See Section VI — B)

D. RECORDING: Connect to the output terminals, observing that pin #2 is at ground. The 503 is designed to drive a 100 millivolt recorder. The CALIBRATE control on the front panel calibrates the output as well as the meter. An internal control R125 OUTPUT CAL is adjusted at the factory to insure tracking between the meter and the output voltage. (See Figure 14)

If it is desired to use a recorder other than 100 millivolts, the output terminals may be shunted with the following values:

Recorder Sensitivity	Resistance Value
50 mv	360 ohms
10 mv	80 ohms
1 mv	360 ohms (tap output 7 ohms from ground)

After the divider is added to the output, recalibrate the instrument on the CAL position. Adjust recorder sensitivity with R125, the internal recorder CAL control.

E. MEASUREMENT OF GROUNDED SAMPLES: It is possible that the test sample may be independently grounded at some point. Since the voltage test lead with the black clip insulator is at chassis ground, errors could arise in measurement. By observing the following procedures this problem can be eliminated:

1. TEMPORARY MEASURE FOR OCCASIONAL MEASUREMENTS: Isolate the Model 503 using a two prong power cord adaptor to remove the ground connection to the power line. Place the instrument so that the cabinet is not touching ground. If the tilt bail is not used, the rubber feet can provide the proper insulation.

2. PERMANENT SET-UP: Should it be necessary to unground the chassis, (such as in rack use) the following modification will facilitate such measurement. This change is applicable only for the milliohm ranges.

Remove the chassis ground connection from pin 4 of T-1 and pin 3 of J-1. Then connect pin 3 of J-1 to pin 4 of T-1. In this way both the voltage and current test leads will be isolated from ground. (Fig. 5)

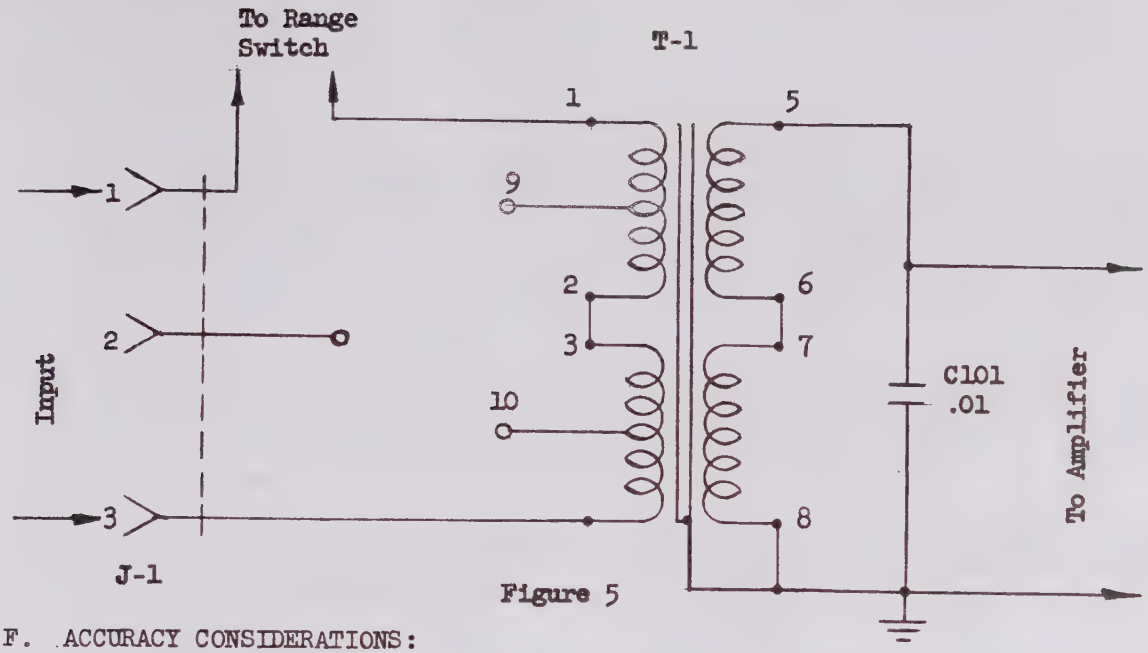


Figure 5

F. ACCURACY CONSIDERATIONS:

1. MEASUREMENT IN THE PRESENCE OF DC CURRENTS: The 503 can measure resistance with dc currents present in the sample. An influencing factor is the amount of current that will saturate the voltmeter input transformer. A 1% error in measurements, using milliohm range settings, will occur if the dc current causes a 20 millivolt drop across the sample. The dc current through the sample can be increased if a capacitor is put in series with a voltmeter lead. The capacitor should be 10 ufd with a voltage rating greater than the dc current source voltage.

With measurements in the range from 1 ohm to 1000 ohms, a 1% error will occur if a current greater than 1 milliampere flows through the current supply circuit. The voltmeter will not be affected unless the source voltage of the dc current exceeds 50 volts.

The dc sample current which will cause 1 ma to flow in the current supply circuit may be computed from the sample resistance and the range resistor in use.

2. INDUCTIVE AND CAPACITIVE EFFECTS: The Model 503 uses an ac measuring system and synchronous demodulation to discriminate against 60 cycle pick-up and to discriminate to a degree against reactive components in the sample. Therefore, usually, no special precautions or shielding are necessary unless the ac fields in the neighborhood of the sample are unusually strong. The usual cause of trouble will be due to electro-magnetic induction. Electro-static pick-up usually is no problem at the impedance involved. A good way to test for pick-up is to remove the current leads and leave the voltage leads attached to the sample. If no reading is seen, there is no cause of concern. If, however, there is a reading, the source of magnetic field must be removed or the sample oriented in such a way as to minimize the reading.

Because of the ac technique employed, inductive and capacitative components in the test impedance may cause some wave-form distortion and erroneous readings. In practice, it has been found that the following method will enable the user to calculate errors introduced by inductance in series with the sample or capacitance across it. Experimentally it can be shown that the error due to a series inductance or shunting capacitance is equal to about 50% of what would be calculated, assuming the shunting or series effect was due to the impedance computed for a 40 cps sine wave.

In the presence of large interfering ac fields, some needle flutter will be noted. This will be due to a beat between the 40 cps carrier frequency and the signal. The average value of the pointer indication will be the correct reading unless the interfering signal is exactly equal in frequency to the carrier. In this case large errors may be encountered. However, since a 40 cps interfering signal is rarely encountered, there will be little likelihood of trouble.

Coupling between the current and voltage leads can cause significant error on the 1 milliohm range. This can be minimized by keeping the voltage and current leads separated and by twisting the pairs of leads to reduce the enclosed area.

3. ERRORS DUE TO SERIES RESISTANCE IN CURRENT AND VOLTAGE LEADS: Series resistance may be appreciable in such cases as resistivity profile measurements, or when low resistance connections to the sample cannot be made. (See Fig. 6)

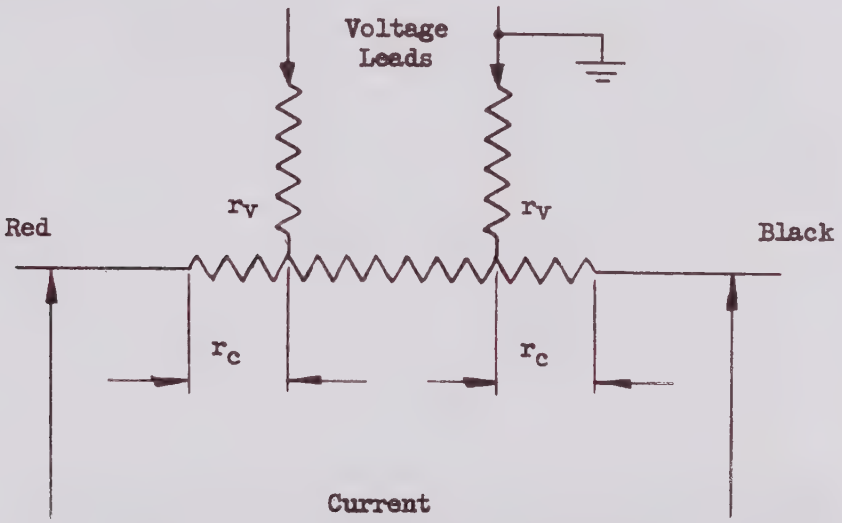


Figure 6

TABLE 3

The tabulated values will give no more than 1% error in measurement;

Range	Total resistance in current leads $2r_c$	Total resistance in voltage leads $2r_v$
Milliohm range settings	1000x full scale range setting	1 ohm
Ohm range settings	33x full scale range setting	10K ohms

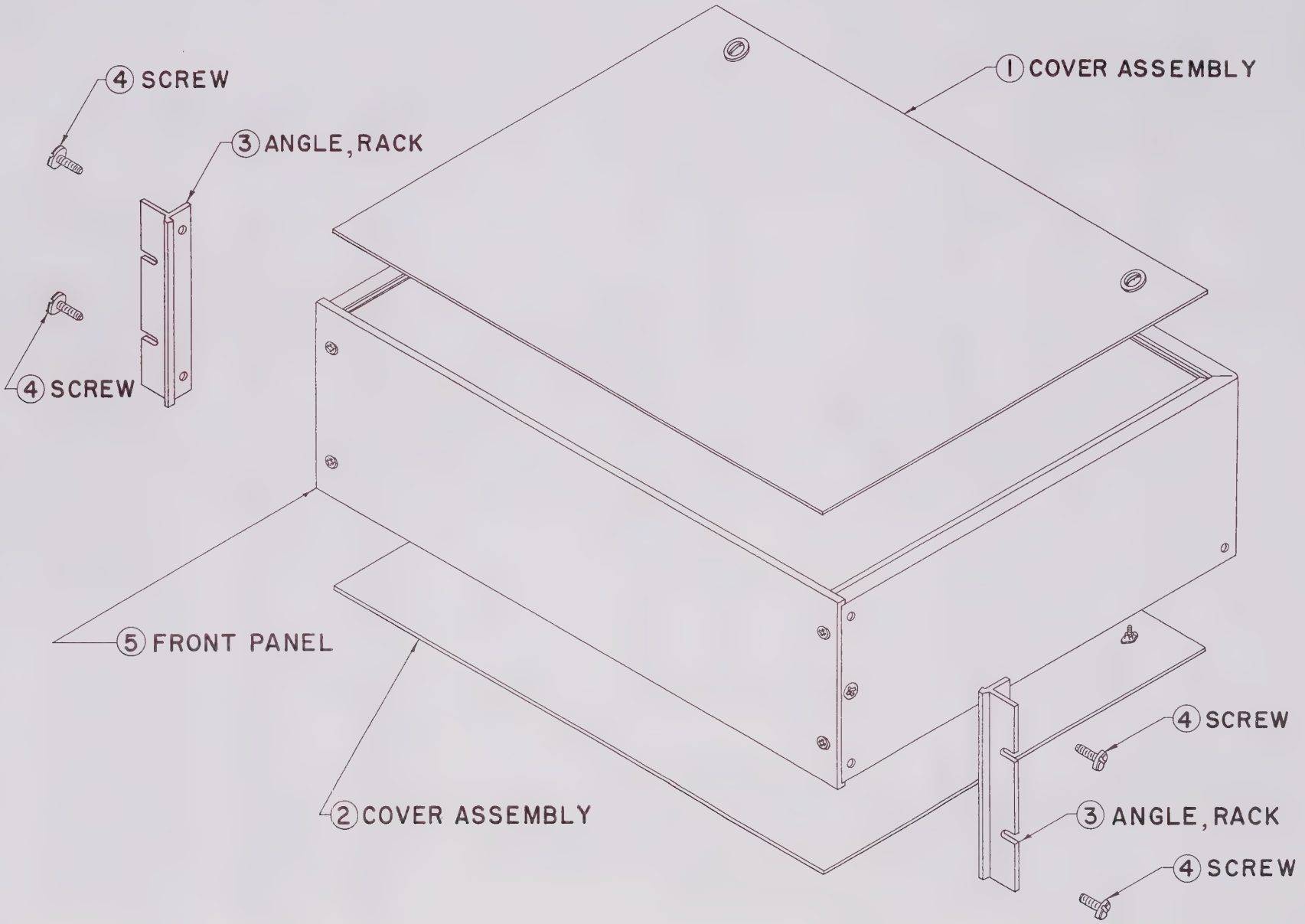

4 SCREW
3 ANGLE, RACK
4 SCREW
1 COVER ASSEMBLY
5 FRONT PANEL
2 COVER ASSEMBLY
4 SCREW
3 ANGLE, RACK
4 SCREW

Figure 7

G. INSTRUCTIONS FOR RACK MOUNTING: The instrument comes set up for bench use with four feet and a tilt-bail. Parts are included for conversion to rack-mount. The rack-mount is for standard EIA (RETMA) 19" width.

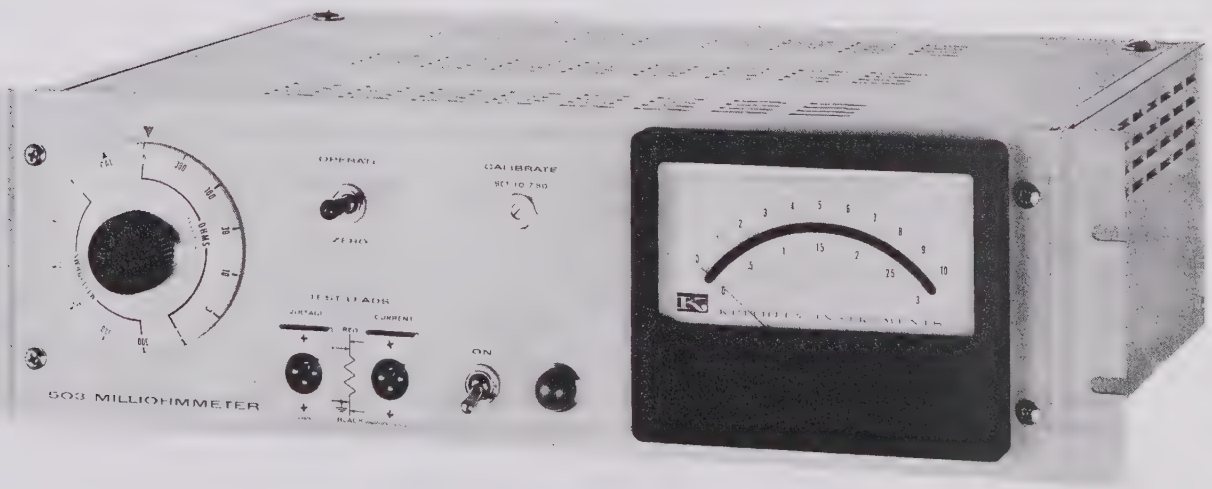
To convert, remove the four #10-32 slotted head screws on the sides of the instrument which hold the cover. Save these screws. Remove the Bottom Cover Assembly (2) which is held in place by two pawl-type fasteners. Remove the four plastic feet and tilt-bail from this cover assembly. Replace cover.

Attach the pair of Rack Angles (3) to the cabinet with the four screws (4) previously removed as shown in the illustration. Insert Top Cover Assembly (1) in place and fasten with pawl-type fasteners at rear. Retain top cover, feet and tilt-bail for future reconversion (See Fig. 7)

The cabinet is now ready for rack-mounting.

PARTS LIST FOR RACK-MOUNTING OF INSTRUMENT CASE
(These parts are packed separately in shipping carton)

Item	Name	Part No.	Quantity
1	Cover Assembly	14623B	1
3	Angle, Rack	14624B	2



SECTION V - CIRCUIT DESCRIPTION

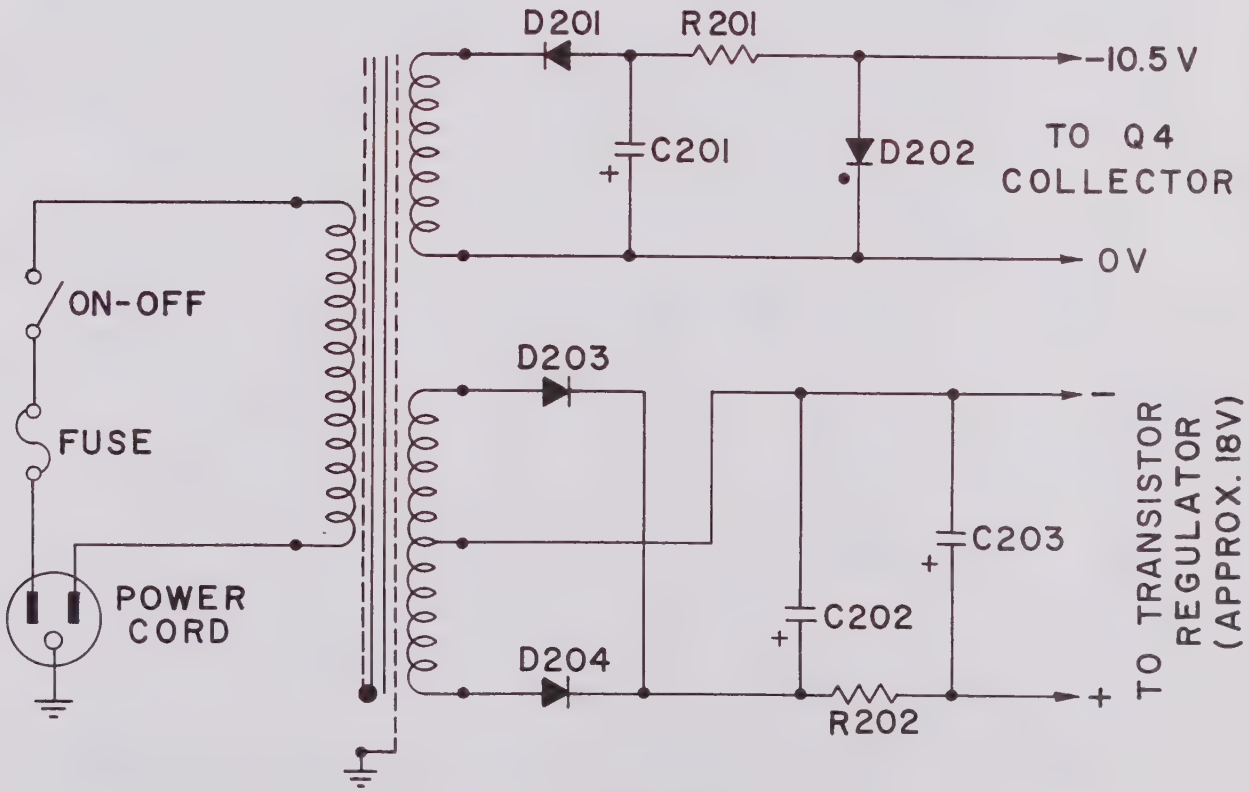
The Model 503 circuit consists of four basic sections; a twelve volt super-regulated power supply, a transistor dc to ac inverter circuit, a four stage high gain vacuum tube amplifier and a silicon diode demodulator.

The twelve volt power supply operates from the line voltage and furnishes a very closely regulated 12 volts. This voltage is used to light the tube filaments and to operate the transistor converter. The converter operates at 40 cps. The output obtained from the converter transformer via various windings, operates the demodulator diodes, supplies the 40 cps test current and the B-plus supply for the ac amplifier via a rectifier-filter system.

The vacuum tube amplifier operates following an input transformer on the milli-ohm ranges and directly amplifies the signal on the ohm ranges. A high degree of gain stability is assured by a substantial feed-back factor and by the use of closely regulated plate and filament supplies.

The output of the amplifier is synchronously demodulated by a silicon diode bridge and the resulting dc signal operates the output circuit and the meter.

A detailed circuit description follows:



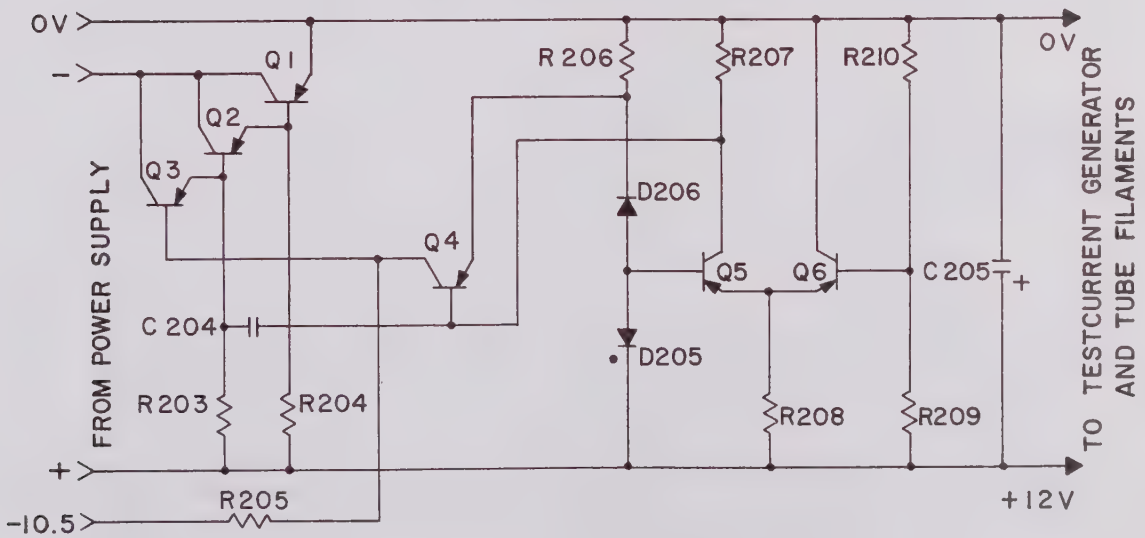
POWER SUPPLY
FIGURE 8

A. POWER SUPPLY: (Fig. 8) The power supply consists of three parts:

1. THE AC POWER TRANSFORMER AND FILTER-RECTIFIER CIRCUITRY: The power transformer, T-2, may be connected for either 117 or 234 volt operation as indicated in the schematic. The secondaries of the transformer supply 18 volts at 1 ampere and 117 volts at 5 ma. The output of the 18 volt winding is full-wave rectified by D203 and D204 and filtered by C202, C203 and R202. The dc voltage developed across C203 is approximately 20 volts. Neither terminal is grounded since the minus terminal of the regulator is grounded at the emitter terminal of Q1.

The output from the 117 v winding is half-wave rectified by D201 and filtered by C201. R201 is a dropping resistor for zener diode D202. This diode is connected between ground and the supply side of the load resistor for transistor Q4. The purpose of this connection will be discussed below.

2. THE SUPER-REGULATED 12 VOLT SUPPLY: (Fig. 9) The unregulated 20 volts dc obtained from rectifiers and the transformer is applied to a solid state regulator consisting of Q1 through Q6 and D202, D205 and D206. Q5 and Q6 form a differential amplifier which compares the voltage across the output of the regulator (C205 is across the output) via divider R210 and R209 to the voltage supplied by zener reference diode D205. If the voltages at the bases of Q5 and Q6 are not equal, the collector voltage of Q5 changes. This change is further amplified by Q4, Q3 and Q2. The signal is finally applied to the base of the series element in the regulator Q1. The signal is always of such magnitude and phase that output voltage is instantaneously brought back to 12 volts. RF-14 is a forward biased diode which sets the emitter voltage of Q4. The collector load resistor of Q4, R205, is returned to minus 10 volts supplied by zener, D202. This extra regulated voltage permits Q4



SUPER REGULATED 12 VOLT SUPPLY

FIGURE 9

to operate at much higher gain than if the collector load were returned to the unregulated side of the supply and permits linear operation of Q4 with widely varying input voltages. This connection makes an important contribution to the performance of the power supply. Q3 and Q2 are cascaded emitter followers whose function is to increase the current gain of the series transistor, Q1. R203 and R204 are added to the circuit to provide stability at high temperatures since they make available a back-bias current equal to the leakage current of the series transistors at a temperature of approximately 80°C. C204 prevents high frequency oscillation of the power supply. The twelve volts at the output of the regulator powers the filaments of V1 and V2 and the pilot lamp DS-1.

3. 40 CPS TRANSISTOR STATIC INVERTER CIRCUIT: (Fig. 10) A portion of the regulated 12 volt power is also used as the supply for a dc converter consisting of the following parts: Transformer T3, transistors Q7 and Q8, diodes D207 and D208, capacitors C206 and C207, and resistors R211, R212 and R213. The operation is as follows: Transistors Q7 and Q8 are connected across the 12 volt supply through their emitters and the center-tap of the 12 volt winding of T3. The bases receive positive feed-back from another winding on T3. The phasing is such that one transistor is driven hard on while the other is cut off. This cycle lasts until the core of T3 reaches saturation. At this point the transformer can no longer keep the on transistor fully conducting and its collector current decreases. This causes the polarity of the feed-back winding to change and the transistor which was cut off now conducts and the conducting transistor is cut off. The frequency of oscillation is controlled by the transformer constants. In this case the frequency was picked to be 40 cps. The ten volts rms secondary winding is used to provide the test signal and provides a 20 volt peak-to-peak square-wave which is used with series resistors R128 through R139 to provide the proper test current for each range. Diodes D101 and D102 limit the output voltage when the current leads are open circuited.

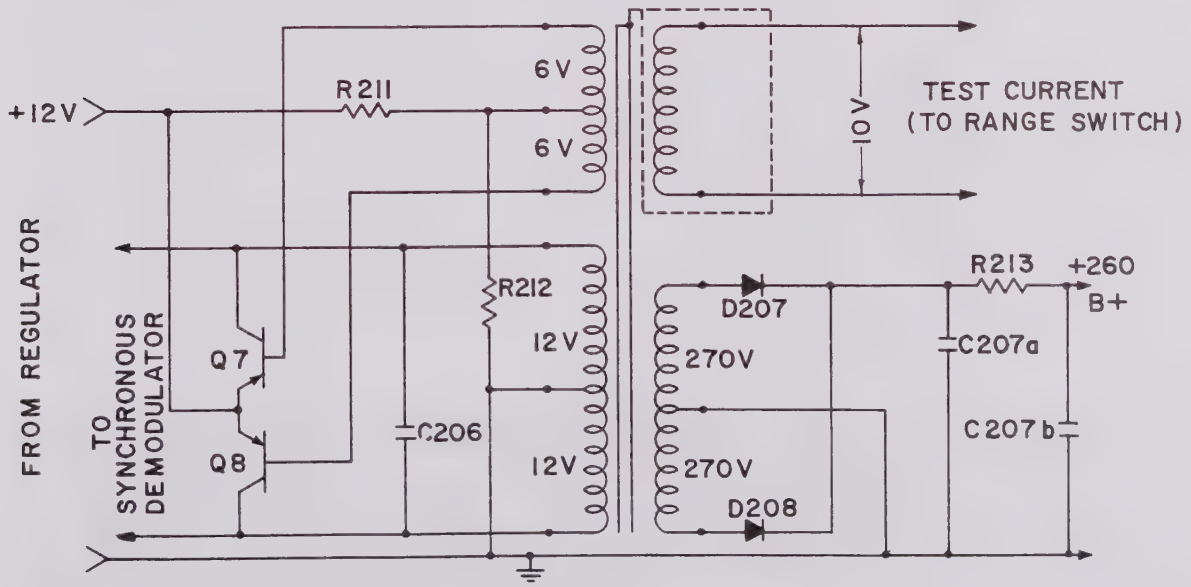
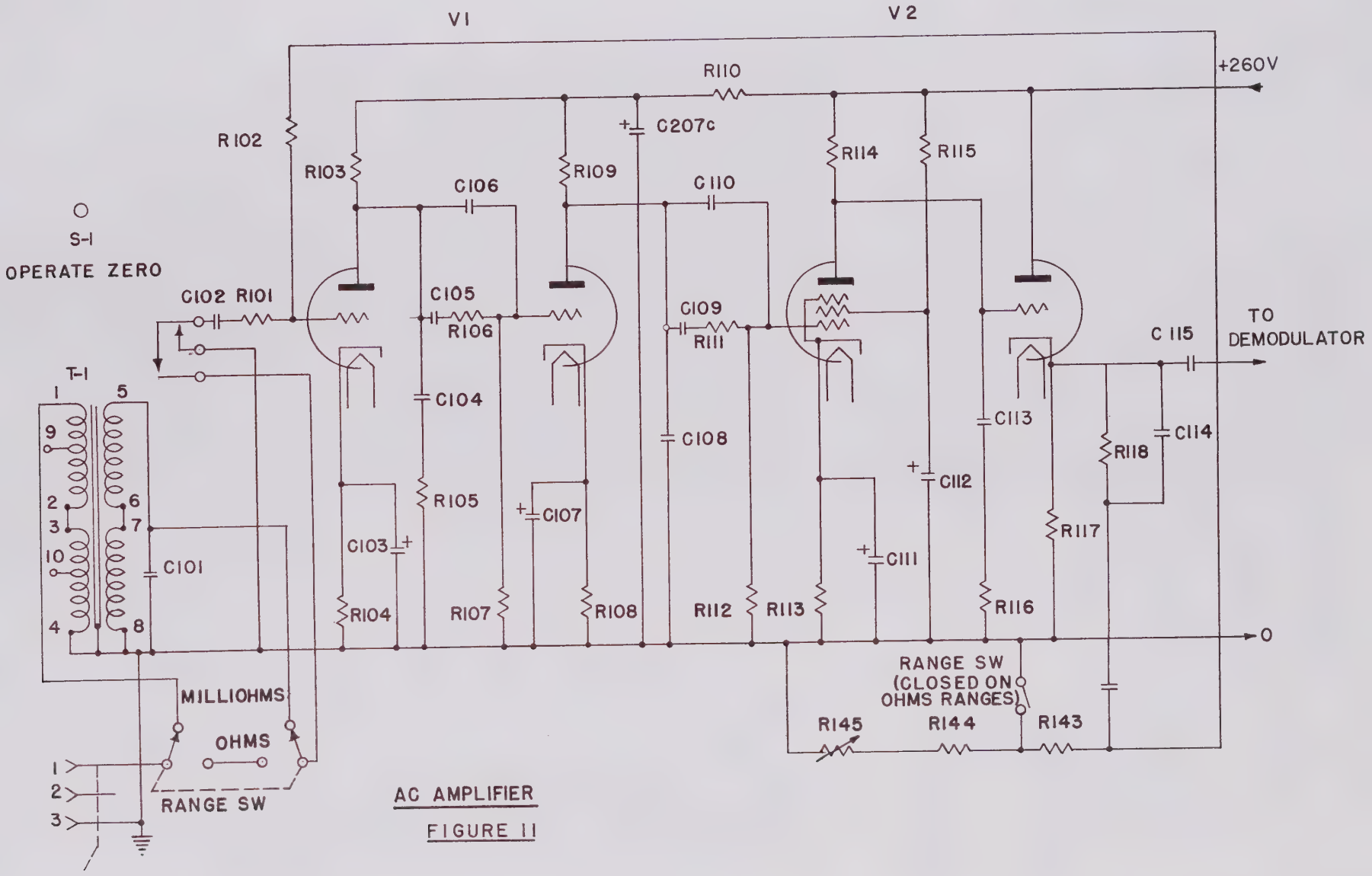


FIGURE 10 TEST CURRENT GENERATOR



AC AMPLIFIER

FIGURE II

The 270 volt winding provides a B+ of 260 volts for the vacuum tube amplifier. The signal is rectified by D207 and D208 and filtered by C207 a and b and R213.

Since the stability of the converter circuit depends only on the stability of the twelve volt power supply, very close regulation is obtained for all potentials used in the circuit. Consequently line voltage variations from 100 to 130 volts have no effect on the instrument.

B. TEST CURRENT GENERATOR: (Fig. 10) As mentioned above, the test current is derived from the 10 volt winding of T-3. Since Q7 and Q8 bottom on each half cycle, the amplitude stability of the signal depends only on the 12 volt supply, and is therefore as stable as the well-regulated 12 volt supply. The circuit is not particularly critical as to frequency or wave-form. However, a nearly perfect square-wave is generated and the frequency is stable to better than a few percent.

The current signal is varied to provide the change in range except between 300 milliohms and 1 ohm where the input transformer is removed from the circuit. The variation is accomplished by switching resistors R128 through R139 with each current range. R140 through R142 are used in conjunction with R128 to keep a constant load on the current source winding to insure a high order of accuracy. Diodes D101 and D102 limit the open-circuit voltage in the current leads to plus or minus 0.5 volts.

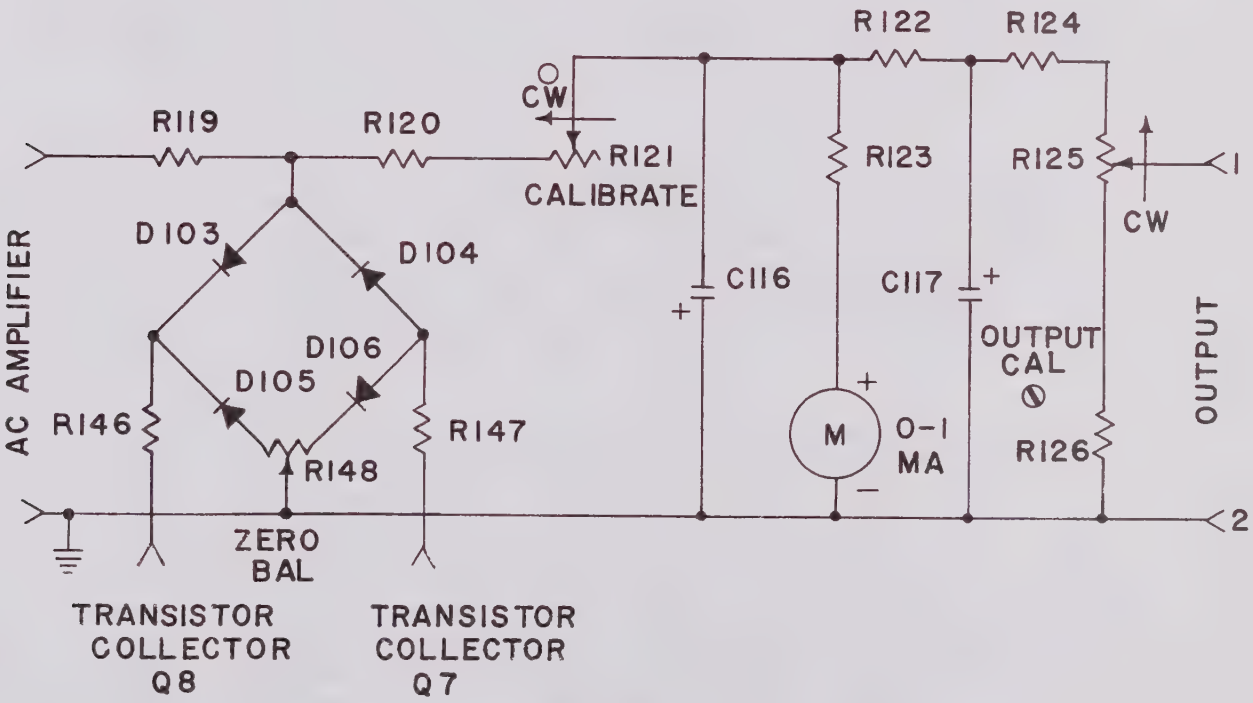
C. THE AC VACUUM-TUBE VOLTMETER: (Fig. 11) On the Milliohm Ranges the input signal passes through transformer T-1. This transformer has approximately a 70:1 step-up ratio and improves the impedance match between the voltage signal and the input grid by a factor of 5000:1. On the ohm ranges, where a larger signal is obtainable, the transformer is switched out so that its input impedance will not shunt the resistance being measured. Accordingly, on the Milliohm ranges, the input resistance is about 200 ohms. On the Ohms ranges, the input resistance is one megohm.

The input signal is fed into the input of the amplifier either through T1 or around it, depending on range, through S1, the OPERATE-ZERO switch. This switch is of the make-before-break variety to prevent switching transients. Following the switch is C102, the input blocking capacitor and R101, the input resistor of the feed-back network. R102 connects the feed-back signal to the input grid so that the input grid signal is the difference between the input signal and the feed-back signal or, as it is usually termed, the error signal. The error signal is amplified by a standard three stage ac amplifier consisting of V1 and V2a. V2b is an output cathode-follower which drives the feed-back loop, R118, R143, R114 and R115; and the meter and output circuits.

The gain of the amplifier is varied slightly to compensate for the absence or presence of the input transformer by shunting R114 and R145 across R143 in the Milliohm position. The MILLIOHM TRIM control is used to calibrate the milliohm ranges. The divided output of R118 and R143 through R145 is applied to R102 and returned to the input, completing the feed-back loop. A feed-back factor of 40 db assures high gain stability. The fact that all potentials used in the amplifier are closely regulated, also helps assure a high degree of gain stability and complete freedom from line bounce.

The amplifier is stabilized against low frequency oscillation by two sets phase-advance interstage couplings, C106, C105, R106 and R107 between the two halves of V1 and by C110, C109, R111 and R112 between V1b and V2a. Each network introduces an appropriate attenuation and phase lead to prevent oscillation and give adequate phase margin. C104, R105; C108; and C113 and R116; are individual high-frequency oscillation stoppers.

D. THE SYNCHRONOUS DEMODULATOR, METER AND OUTPUT: (Fig. 12) The output of V2b is coupled through C115 and R119 to a demodulator bridge circuit consisting of D103 through D106. The bridge is driven through R146 and R147 from the collectors of Q7 and Q8. Since the center tap of the collector winding is at ground, the drive signal is balanced to ground. When the junction of D103 and D105 is positive with respect to the junction of D104 and D106, the diodes are conducting and the junction between R119 and R120 is effectively grounded. When the polarity is reversed, the bridge is open circuited. Therefore, the signal is rectified in this manner. The output travels through R120, R121 and then is split. Part of the current drives the meter and the remainder the output. R121 is the calibration control. It is located on the front panel. On the CAL position of the range switch, R127 is switched in and this potentiometer is used to correct the meter reading if necessary. R125 allows calibration of the recorder terminal.



SYNCHRONOUS DEMODULATOR
METER-OUTPUT
FIGURE 12

SECTION VI - SERVICING INFORMATION

The Model 503 should not require periodic maintenance. Occasional verification of either the calibration (Section IV-C) and the dc balance (Section VI-E) should reveal any need for adjustment. If difficulty is encountered, read completely the following material:

A. Trouble Shooting Guide

Servicing is quite straight forward as the 503 employs only two vacuum tubes and eight transistors, all of which are conservatively operated within their ratings. No matched or critically selected components are used.

The usual caution should be observed when soldering to the printed circuit board as excessive heat will damage the board.

In servicing, bear in mind all operating voltages are obtained from the 12 volt transistor regulator, either directly or through the transistor inverter.

Reference should be made to Circuit Schematic DR 146280 for voltage values and other circuit parameters.

In case of complete failure to operate, the fuse, line cord and power source should all be checked. If these are all found satisfactory, use the following detailed service procedure to isolate the trouble:

1. POWER SUPPLY:

   a. THE AC POWER TRANSFORMER AND FILTER RECTIFIER CIRCUITRY (Figure 8): Set the RANGE SWITCH to the 3 milliohm position with ZERO-OPERATE switch in ZERO position. Remove transistor Q-1 from the circuit and measure the voltage across C203. (See schematic notes for recommended type VTVM). If approximately 25 volts dc is indicated, this portion of the circuit is in proper work-order. Note that neither terminal of C203 is grounded.

      Measure voltage across D202, which should be between -9 to -12 volts with respect to ground. If not, check diodes D201 and D202.

   b. THE SUPER REGULATED 12 VOLT SUPPLY (See Figure 9): Replace transistor Q-1 in the circuit. Determine that the regulated 12 volts across C205 does not vary more than 5 mv with line voltages from 105 volts to 125 volts. Use a variable autotransformer to supply the line voltage. (General Radio Variac)

      If no voltage is present or the 12 volts are not regulated, check components in this portion of the circuit.

2. 40 CPS TRANSISTOR INVERTER (Figure 10): With the range switch set at 3 milliohms, connect the current test leads to an oscilloscope. Observe a 40 cps square wave with a peak to peak amplitude of about 20 volts. If this is present, measure +260 volts dc across C207b. If no square wave is observed, or the B+ is absent, check the components in this portion of the circuit.

NOTE: FOR SECTIONS 3 AND 4 THE RANGE SWITCH SHOULD BE IN CAL POSITION WITH THE ZERO-OPERATE SWITCH IN THE OPERATE POSITION.

3. THE AC VACUUM TUBE VOLTMETER. (Figure 11): Be sure both vacuum tube filaments are heated and the pilot lamp is lit. Since the pilot lamp is in parallel with the filament of V1 and the combination is in series with the filament of V2 across the 12 volt regulator, some service information is provided by its brilliance. If it lights normally, it may be assumed the supply is working properly. If it is brighter than normal, V1 is probably burned out. If the lamp is not lit, either V2 is burned out, or the pilot itself is open. The instrument will operate without the pilot lamp, but since the life of V1 will be reduced, it should be replaced.

If it is determined the tubes are operating properly, proceed as follows: Measure at the junction of C102 and R101 a 4 millivolt peak to peak square wave. This indicates the test current is properly reaching the amplifier through the range switch. Should there be no signal, or one of improper magnitude, inspect the range switch for faulty operation or component failure.

Next, check the voltage between pin 8 of V2 and ground. This should be a square wave voltage of about 10 volts peak to peak. A distortion in/or absence of this signal indicates a faulty AC amplifier.

4. SYNCHRONOUS DEMODULATOR - METER OUTPUT (Figure 12): Connect an oscilloscope to the junction of R-119 and R-120 and compare this wave form with Figure 13.

Figure 13

A distortion or absence of this wave form is an indication of a faulty demodulator.

B. CALIBRATION: The procedure of Section IV-C calibrates the 503 on the 1000 range. Other ranges should be within specification once this range is properly calibrated. If the user wishes to further verify the CALIBRATION, or to calibrate for a given range or point, the following procedures are recommended:

1. OHM RANGES: A standard resistor of at least 0.05% accuracy is recommended. The standard should be selected to 3/4 of full scale of range in question, or to the value of the measurement to be made. The slotted control on the front panel will adjust the meter needle for proper deflection.

2. MILLIOHM RANGES: To calibrate the milliohm ranges, an appropriate low value standard resistor is required. Leeds & Northrup Type 4221-B, 100 milliohms; Type 4222-B - 10 milliohms; and Type 4223-B, 1 milliohm are all suitable. Using one of these resistors or their equivalent, adjust the "MILLIOHM CAL" (Figure 14) for the proper meter reading.

HOW TO ORDER PARTS

Parts may either be ordered from Keithley Instruments directly, or from the Manufacturers where they are specified in the parts list. All structural parts are manufactured by Keithley.

When ordering from Keithley, include the instrument Model No. and its Serial No. as well as a complete description of the part with its corresponding Part No. and circuit designation.

Send Orders to:

Keithley Instruments, Inc.
12415 Euclid Avenue
Cleveland 6, Ohio

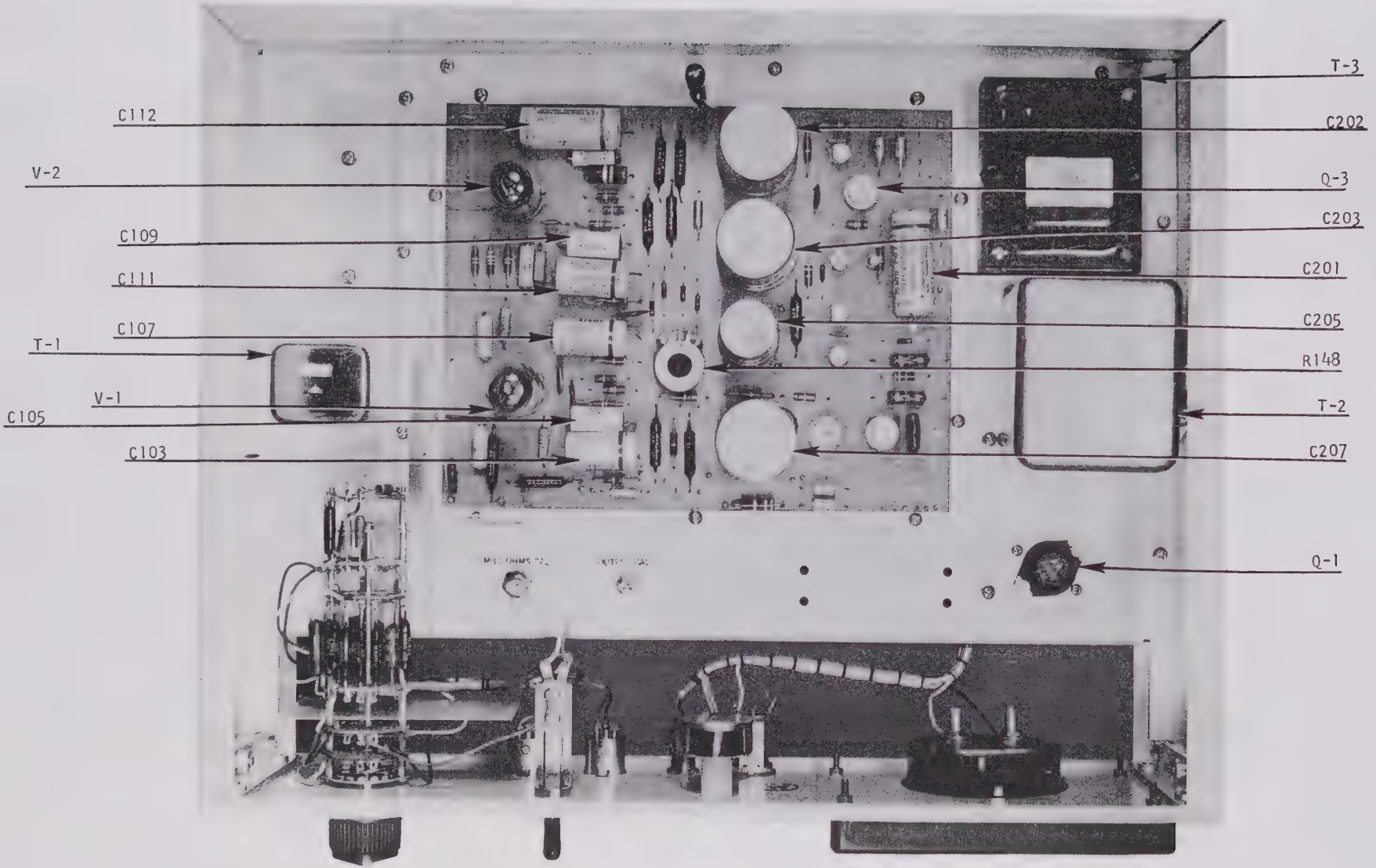

C112
V-2
C109
C111
C107
T-1
V-1
C105
C103
T-3
C202
Q-3
C203
C201
C205
R148
T-2
C207
Q-1

Figure 14

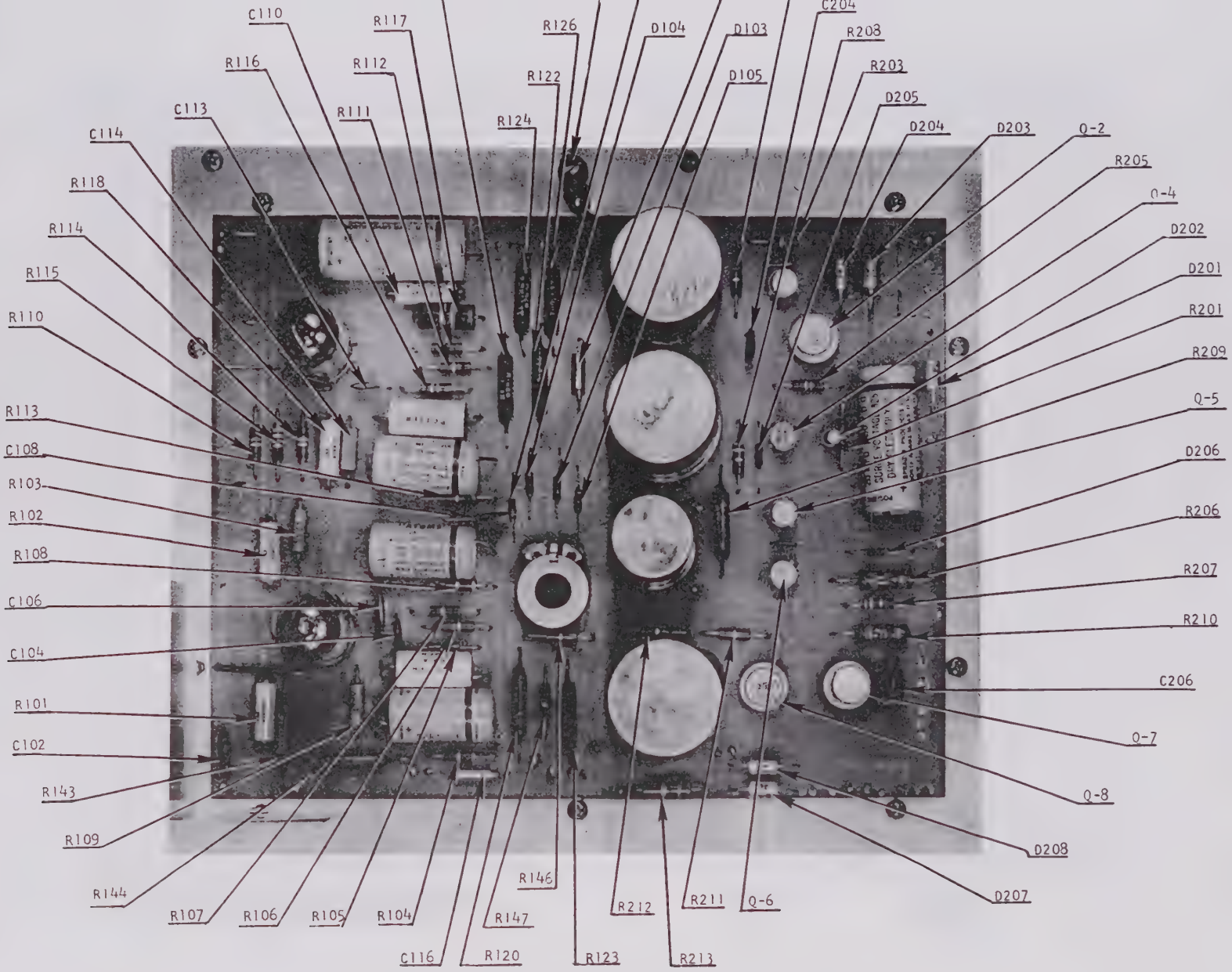

C110
R117
R126
D104
D103
C204
R208
R116
R112
R122
D105
R203
C113
R111
R124
D205
D204
D203
Q-2
C114
R205
R118
Q-4
R114
D202
R115
D201
R110
R201
R209
R113
Q-5
C108
D206
R103
R102
R206
R108
R207
C106
R210
C104
C206
R101
Q-7
C102
R143
Q-8
R109
D208
R144
D207
R107
R106
R105
R104
R146
R147
R212
R211
Q-6
C116
R120
R123
R213

Figure 15

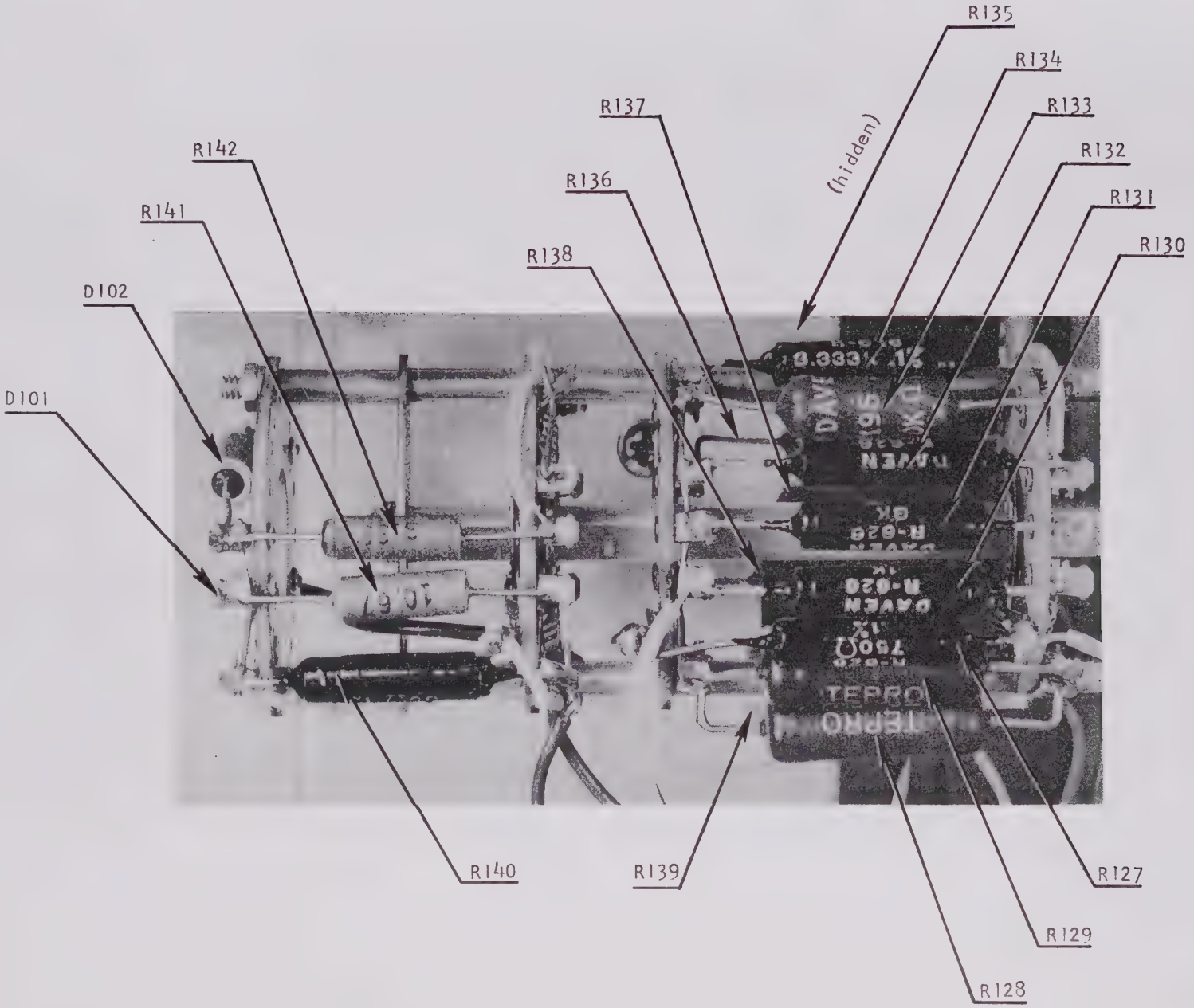


Figure 15 Range Switch

REPLACEABLE PARTS LIST

LIST OF SYMBOLS AND ABBREVIATIONS

a	Amperes
Av	Air Variable
CbF	Carbon Film
Cer	Ceramic Disc
CerV	Ceramic Variable
CompV	Composition Variable
DCb	Deposited Carbon
EC	Electrolytic Can
ETB	Electrolytic Tubular
ETT	Electrolytic Tantalum
f	farad
GMV	Guaranteed Minimum Value
h	Henry
K	Kilo (10^3)
Ω	Ohms
M	mega (10^6)
m	milli (10^{-3})
MtF	Metal Film
My	Mylar
p	pico (10^{-12})
PC	Paper Can
Prec	Precision
PT	Paper Tubular
PV	Plastic Variable
R	Resistor
Sw	Switch
u	micro (10^{-6})
V	Volts
Var	Variable
w	Watt
WW	Wire Wound
WWVar	Variable Wire Wound

CAPACITORS

Circuit Desig.	Value	Rating	Type	Keithley Part No.
C-101	0.01 uf	600V	Cer	C47-.01
C-102	0.1 uf	50V	My	C41-0.1
C-103	100 uf	15V	ETB	C11-100
C-104	220 pf	600V	Cer	C22-220
C-105	1 uf	200V	My	C66-1.0
C-106	0.005 uf	600V	Cer	C22-.005
C-107	100 uf	15V	ETB	C11-100
C-108	0.02 uf	600V	Cer	C22-.02
C-109	1 uf	200V	My	C66-1.0
C-110	.047 uf	200V	My	C66-.047
C-111	100 uf	15V	ETB	C11-100
C-112	20 uf	250V	ETB	C27-20
C-113	.0022 uf	600V	Cer	C22-.0022
C-114	270 pf	300V	Mica	C21-270
C-115	10 uf	200V	PC	C69-10
C-116	56 uf	6V	ETT	C70-56
C-117	56 uf	6V	ETT	C70-56
C-201	20 uf	250V	ETB	C27-20
C-202	500 uf	50V	EC	C57-500
C-203	500 uf	50V	EC	C57-500
C-204	0.01 uf	600V	Cer	C22-.01
C-205	500 uf	25V	EC	C58-500
C-206	0.22 uf	50V	My	C41-0.22
C-207	40/40/20 uf	450V	EC	C33-40/40/20

DIODES, TUBES AND TRANSISTORS

Circuit Desig.	Component	Type	Number	Keithley Part No.
D-101	Diode	Silicon	1N3253	RF-20
D-102	Diode	Silicon	1N3253	RF-20
D-103	Diode	Silicon	1N482	RF-14
D-104	Diode	Silicon	1N472	RF-14
D-105	Diode	Silicon	1N482	RF-14
D-106	Diode	Silicon	1N482	RF-14
D-107	Diode	Silicon	1N482	RF-14
D-201	Diode	Silicon	1N3255	RF-17
D-202	Diode	Zener	1N1314	DZ-2
D-203	Diode	Silicon	1N3253	RF-20
D-204	Diode	Silicon	1N3253	RF-20
D-205	Diode	Zener	1N936	DZ-5
D-206	Diode	Silicon	1N482	RF-14
D-207	Diode	Silicon	1N3256	RF-22
D-208	Diode	Silicon	1N3256	RF-22
Q-1	Transistor		2N1535	TG-7
Q-2	Transistor		2N1183	TG-11
Q-3	Transistor		2N1381	TG-8
Q-4	Transistor		2N1381	TG-8
Q-5	Transistor		2N1381	TG-8
Q-6	Transistor		2N1181	TG-8
Q-7	Transistor		2N1183	TG-11
Q-8	Transistor		2N1183	TG-11
V-1	Vacuum Tube		12AX7	EV-12AX7
V-2	Vacuum Tube		6U8A	EV-6U8A

RESISTORS

Circuit Desig.	Value	Rating	Type	Keithley Part No.
R-101	1M	1%, ½ W	MtF	R53-1M
R-102	1M	1%, ½ W	MtF	R53-1M
R-103	470K	1%, ½ W	DCb	R12-470K
R-104	4.7K	10%, ½ W	Comp	R1-4.7K
R-105	12K	10%, ½ W	Comp	R1-12K
R-106	10M	10%, ½ W	Comp	R1-10M
R-107	1M	10%, ½ W	Comp	R1-1M
R-108	4.7K	10%, ½ W	Comp	R1-4.7K
R-109	470K	1%, ½ W	DCb	R12-470K
R-110	15K	10%, ½ W	Comp	R1-15K
R-111	10M	10%, ½ W	Comp	R1-10M
R-112	1M	10%, ½ W	Comp	R1-1M
R-113	470	10%, ½ W	Comp	R1-470
R-114	100K	10%, ½ W	Comp	R1-100K
R-115	390K	10%, ½ W	Comp	R1-390K
R-116	10K	10%, ½ W	Comp	R1-10K
R-117	10K	10%, 2 W	Comp	R3-10K
R-118	1M	1%, ½ W	MtF	R43-1M
R-119	1K	1%, 1 W	WW	R58-1K
R-120	1.8K	1%, 1 W	WW	R58-1.8K
R-121	1K	2 W	WWVar	RP3-1K
R-122	2.5K	1%, 1 W	WW	R58-2.5K
R-123	500	1%, 1 W	WW	R58-500
R-124	2.5K	1%, 1 W	WW	R58-2.5K
R-125	200	2 W	WWVar	RP3-200
R-126	700	1%, 1 W	WW	R58-700
R-127	750	0.1%, ½ W	WW	R70-750
R-128	100	0.1%, 2 W	WW	R72-100
R-129	300	0.1%, 2 W	WW	R72-300
R-130	1K	0.1%, ½ W	WW	R70-1K
R-131	3K	0.1%, 1 W	WW	R70-3K
R-132	10K	0.1%, 1 W	WW	R70-10K
R-133	30K	0.1%, ¼ W	WW	R56-30K
R-134	3.333K	0.1%, ¼ W	WW	R70-3.333K
R-135	33.33K	0.1%, ¼ W	WW	R56-33.33K

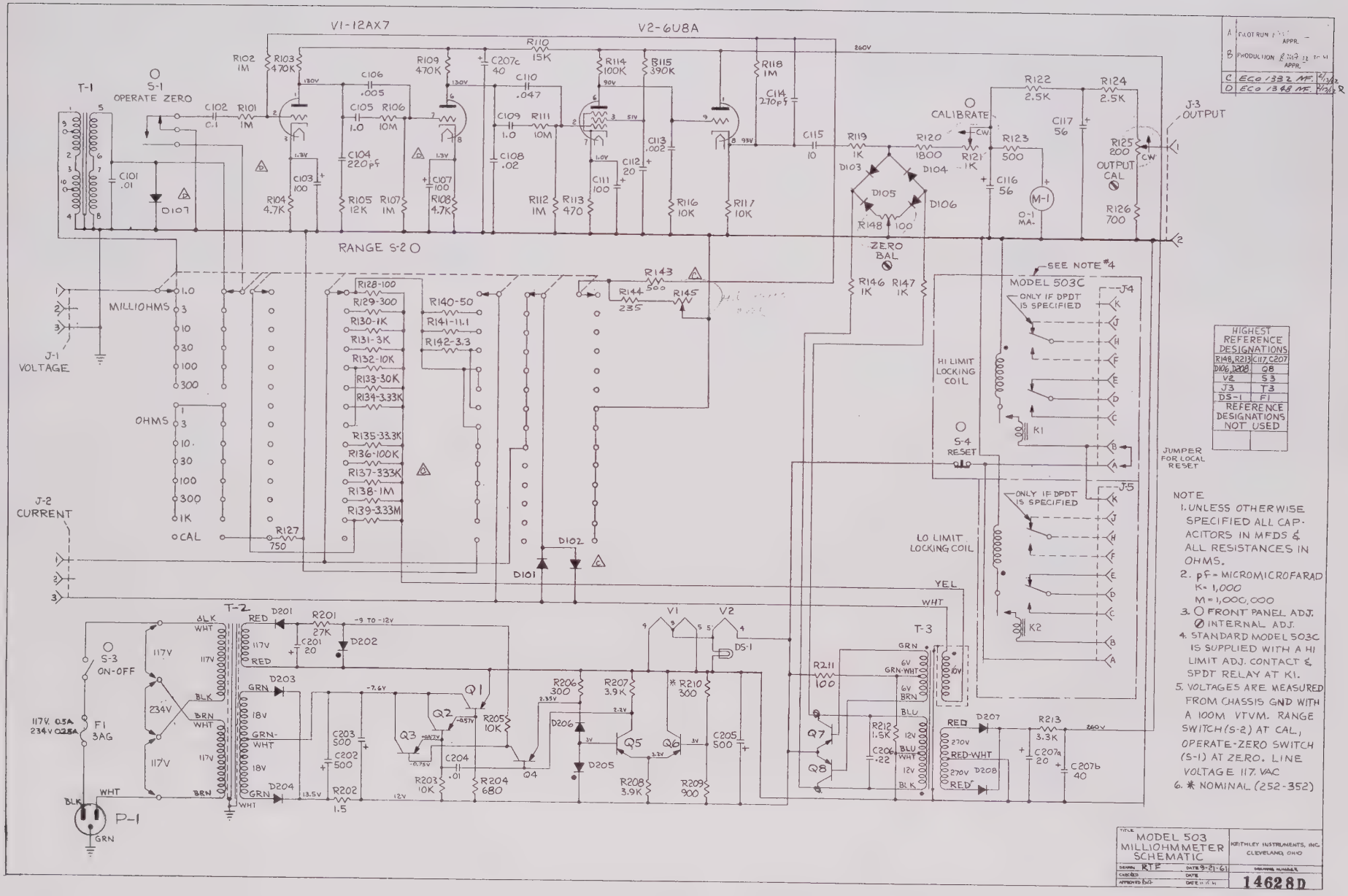
RESISTORS

Circuit Desig.	Value	Rating	Type	Keithley Part No.
R-136	100K	0.1%, ¼ W	WW	R56-100K
R-137	333.3K	0.1%, ¼ W	WW	R56-333.3K
R-138	1M	0.1%, ½ W	WW	R57-1M
R-139	3.333M	0.1%, 1 W	MtF	R59-3.333M
R-140	50	1%, 1 W	WW	R58-50
R-141	11.1	1%, ½ W	DCb	R12-11.1
R-142	3.33	1%, ½ W	DCb	R12-3.33
R-143	500	1%, 1 W	WW	R58-500
R-144	235	1%, 1 W	WW	R58-235
R-145	100	2 W	WWVar	RP3-100
R-146	1K	10%, ½ W	Comp	R1-1K
R-147	1K	10%, ½ W	Comp	R1-1K
R-148	100		CarVar	RP12-100
R-201	27K	10%, ½ W	Comp	R1-27K
R-202	1.5	5%, 10 W	WW	R5-1.5
R-203	10K	10%, ½ W	Comp	R1-10K
R-204	680	10%, ½ W	Comp	R1-680
R-205	10K	10%, ½ W	Comp	R1-10K
R-206	300	1%, 1 W	WW	R58-300
R-207	3.9K	10%, ½ W	Comp	R1-3.9K
R-208	3.9K	10%, ½ W	Comp	R1-3.9K
R-209	900	1%, 1 W	WW	R58-900
R-210	300*	1%,	WW	R58-(252-352)*
R-211	100	10%, ½ W	Comp	R1-100
R-212	1.5K	10%, ½ W	Comp	R1-1.5K
R-213	3.3K	10%, 1 W	Comp	R2-3.3K

* = Nominal - 300 ohms

MISCELLANEOUS ITEMS

Circuit Desig.	Description	Keithley Part No.
DS-1	Lamp, Incandescent #47, 6.3V @ 0.15a	PL-4
F-1	Fuse, 3AG, 117V, 0.5a	FU-6
	234V, 0.25a	FU-9
J-1	Receptacle, 3 terminal	CS-71
J-2	Receptacle, 3 terminal	CS-71
J-3	Receptacle, 2 terminal	CS-32
J-4	Receptacle, 9 terminal (503 only)	CS-81
K-1	Relay (503C only)	RL-3
M-1	Meter, 1.0 ma, ± 5%, ½% tracking	ME-39
	Adjustable high limit locking contact (503C only)	ME-42
P-1	Line Cord, 3 wire	CO-2
S-1	Operate-Zero Switch, 2 pos. lever	SW-59
S-2	Range Switch, 6 deck, 14 pos.	SW-114
S-3	Power Switch, SPST Toggle	~~SW-14~~
S-4	Reset Switch, Push Button (503C only)	SW-35
T-1	Input Transformer	TR-53
T-2	Power Transformer	TR-45
T-3	Inverter Transformer	TR-55
	Fuse Holder	FH-3
	Pilot Lamp Assembly	PL-16R
	Knob Assembly (for Range Switch)	14528-A
	Test Lead Set	5031
	Mating plug for input connector	CS-72
	Mating plug for output connector	CS-33


V1-12AX7
V2-6U8A
T-1
S-1 OPERATE ZERO
R110 15K
260V
R102 1M
R103 470K
R109 470K
C207c 40
C110 .047
R114 100K
R115 390K
R118 1M
C114 270pF
C106 .005
C105 1.0
R106 10M
C109 1.0
R111 10M
C108 .02
C104 220pF
C103 100
C107 100
C112 20
C111 100
C113 .002
C115 10
R104 4.7K
R105 12K
R107 1M
R108 4.7K
R112 1M
R113 470
R116 10K
R117 10K
C101 .01
C102 .1
R101 1M
D107
CALIBRATE
R119 1K
R120 1800
R121 1K
R122 2.5K
R123 500
R124 2.5K
R125 200
OUTPUT CAL
C117 56
C116 56
D103
D104
D105
D106
R148 100
M-1
0-1 MA.
R126 700
J-3 OUTPUT
ZERO BAL
RANGE S-2
R143 500
R144 235
R145
R146 1K
R147 1K
SEE NOTE #4
MODEL 503C
J-4
ONLY IF DPDT IS SPECIFIED
HI LIMIT LOCKING COIL
K1
S-4 RESET
JUMPER FOR LOCAL RESET
J-5
LO LIMIT LOCKING COIL
K2
J-1 VOLTAGE
MILLIOHMS
OHMS
CAL
R128-100
R129-300
R130-1K
R131-3K
R132-10K
R133-30K
R134-33.3K
R135-33.3K
R136-100K
R137-333K
R138-1M
R139-3.33M
R140-50
R141-11.1
R142-3.3
R127 750
D101
D102
J-2 CURRENT
T-2
S-3 ON-OFF
117V. 0.5A
234V 0.25A
F1 3AG
P-1
D201
R201 27K
C201 20
D202
D203
D204
C202 500
C203 500
R202 1.5
R203 10K
C204 .01
R204 680
Q1
Q2
Q3
Q4
R205 10K
R206 300
R207 3.9K
R208 3.9K
R209 900
R210 300
D205
D206
Q5
Q6
C205 500
V1
V2
DS-1
T-3
R211 100
Q7
Q8
R212 1.5K
C206 .22
D207
D208
R213 3.3K
C207a 20
C207b 40
HIGHEST REFERENCE DESIGNATIONS
R148, R213, C117, C207
D106, D208
Q8
V2
S3
J3
T3
DS-1
F1
REFERENCE DESIGNATIONS NOT USED
NOTE
1. UNLESS OTHERWISE SPECIFIED ALL CAPACITORS IN MFDS & ALL RESISTANCES IN OHMS.
2. pF = MICROMICROFARAD
K = 1,000
M = 1,000,000
3. ○ FRONT PANEL ADJ.
⊘ INTERNAL ADJ.
4. STANDARD MODEL 503C IS SUPPLIED WITH A HI LIMIT ADJ. CONTACT & SPDT RELAY AT K1.
5. VOLTAGES ARE MEASURED FROM CHASSIS GND WITH A 100M VTVM. RANGE SWITCH (S-2) AT CAL, OPERATE-ZERO SWITCH (S-1) AT ZERO. LINE VOLTAGE 117 VAC
6. * NOMINAL (252-352)
A PILOT RUN APPR.
B PRODUCTION APPR.
C ECO 1332 ME
D ECO 1348 ME
MODEL 503 MILLIOHMMETER SCHEMATIC
KEITHLEY INSTRUMENTS, INC. CLEVELAND, OHIO
DRAWN RTF DATE 9-21-61
CHECKED DATE
APPROVED ENG. DATE
DRAWING NUMBER
14628D

Circuit Desig.	Value	Rating	Type	Keithley Part No.
R-201	27K	10%, 1 w	Comp.	R2-27K

CHANGE NOTICE

August 20, 1962 Model 503 Milliohmmeter

Replaceable Parts List

The following diodes are changed to:

D203	Diode	Silicon	1N1563A	RF-19
D204	Diode	Silicon	1N1563A	RF-19